Welding Residual Stress Analysis of Narrow-Gap Weld

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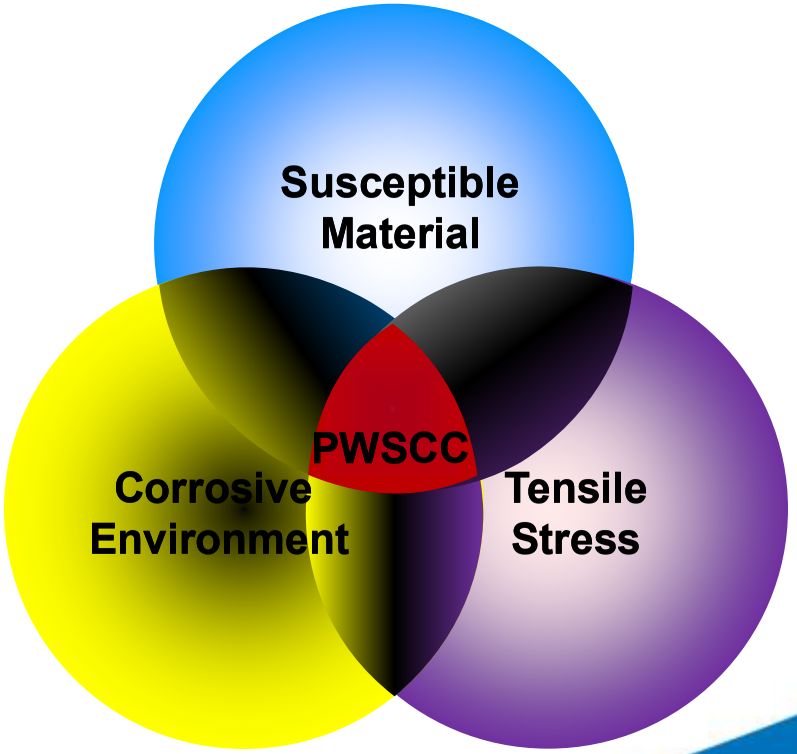
Outline

- Introduction
- Pipe and Weld Geometry
- Analysis Summary
- Stress Results
- Discussion
- Conclusions

Introduction

Primary Water Stress Corrosion Cracking (PWSCC)

- 3 necessary conditions must exist simultaneously:
  - Susceptible Material
  - Corrosive Environment
  - Tensile Stress



- Welding residual stress can be the primary mechanical driving force for PWSCC

- PWSCC is a time dependent degradation mechanism

Introduction (continued)

RES WRS Analysis Support to NRC Offices

- NRR – Addressing PWSCC Issues
  - Multiple WRS and flaw evaluation calculations performed
    - Examples: North Anna, Wolf Creek, etc.
  - ASME Code actions, Code Cases
    - Examples: N-754, N-740, WRS Guidance Appendix (non-mandatory)
  - PWSCC mitigation reviews
    - Examples: MSIP, Inlay, Overlay, EWR
  - Safety evaluation input for EPRI MRP-169 review
  - WRS Validation Program

- NMSS – Addressing Chloride Induced SCC Issues
  - Dry storage container WRS analysis performed

Introduction (continued)

Narrow Gap Weld Analysis

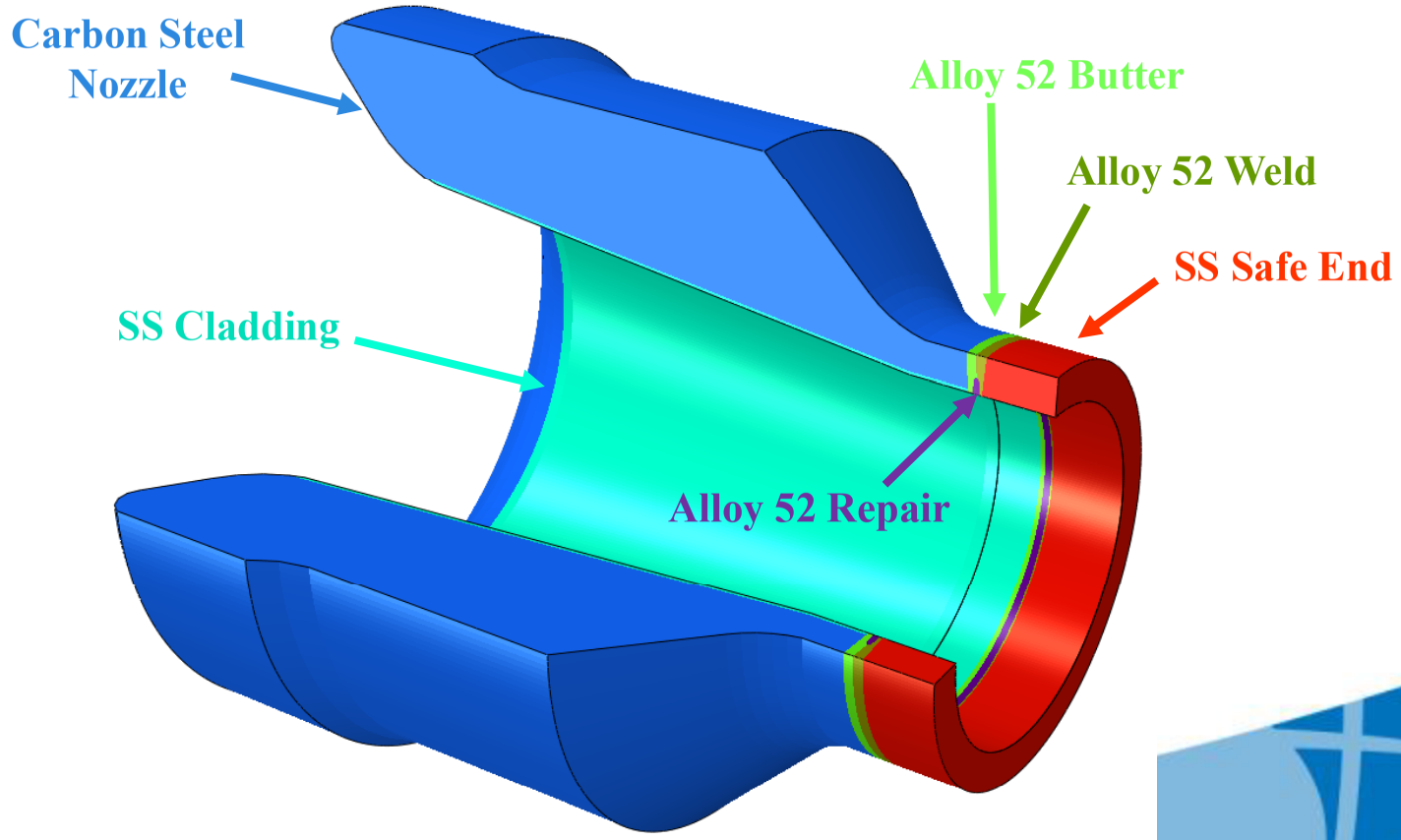
- RV nozzle fabrication flaw indications were identified and repaired from the ID

- NRO requested RES to perform weld residual stress analysis of nozzle-to-safe-end weld with repair

Pipe and Weld Geometry

Narrow Gap Weld Analysis

- Axi-symmetric model used in analysis
  - Revolved model shown here for illustration



Analysis Summary

Narrow Gap Weld Analysis

- Model simulates pass by pass weld deposition process
  - Butter heat treatment results in low stresses, so the butter weld is not analyzed
- Sequentially coupled thermal / structural analysis
- Axi-symmetric geometry
- Temperature-dependent material properties
  - Isotropic/kinematic mixed strain hardening

Analysis Summary (cont'd)

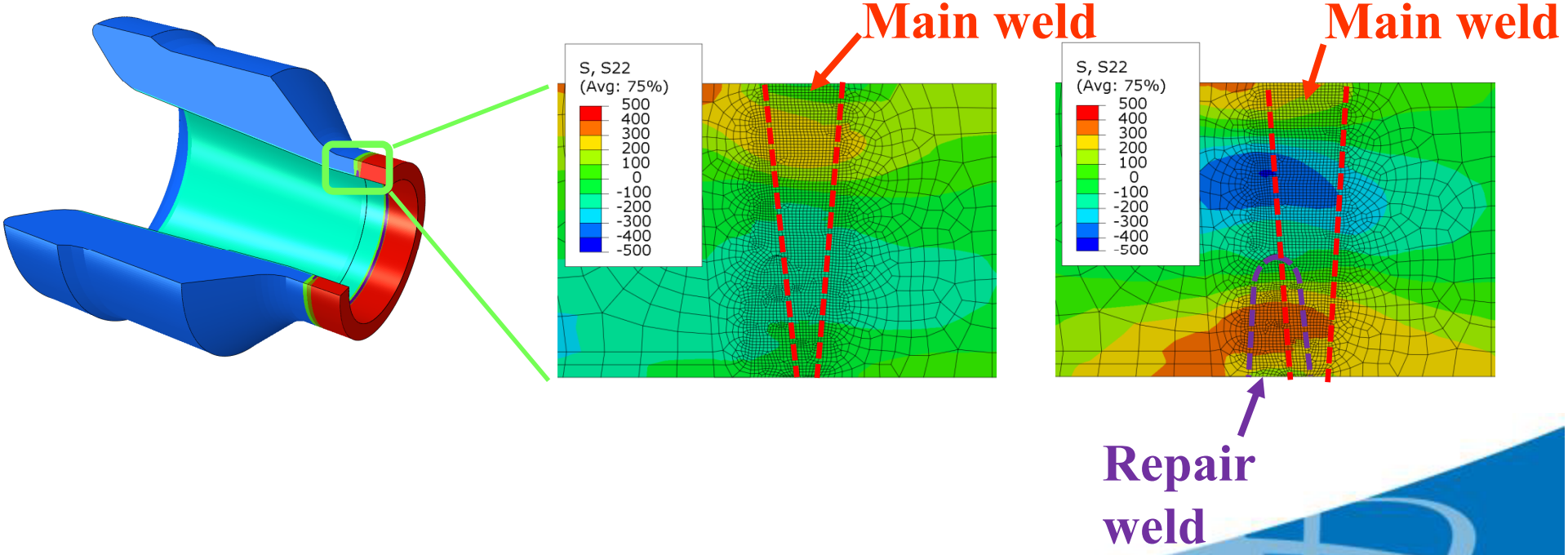
Narrow Gap Weld Analysis

- Weld parameters extracted from actual configuration
- Weld current applied is average of base and peak current
- Welding heat addition simulates time dependence of moving arc
- Stress values reported are at room temperature

Stress Results

Narrow Gap Weld Analysis

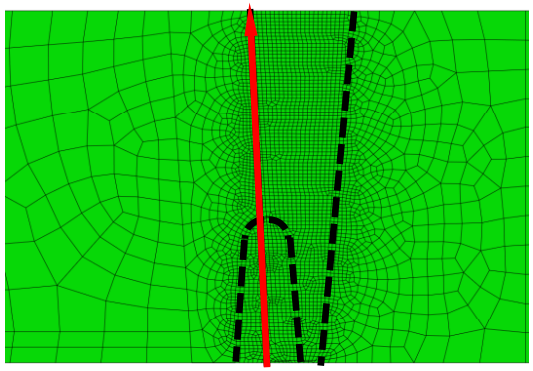
- Axial stresses before and after repair weld



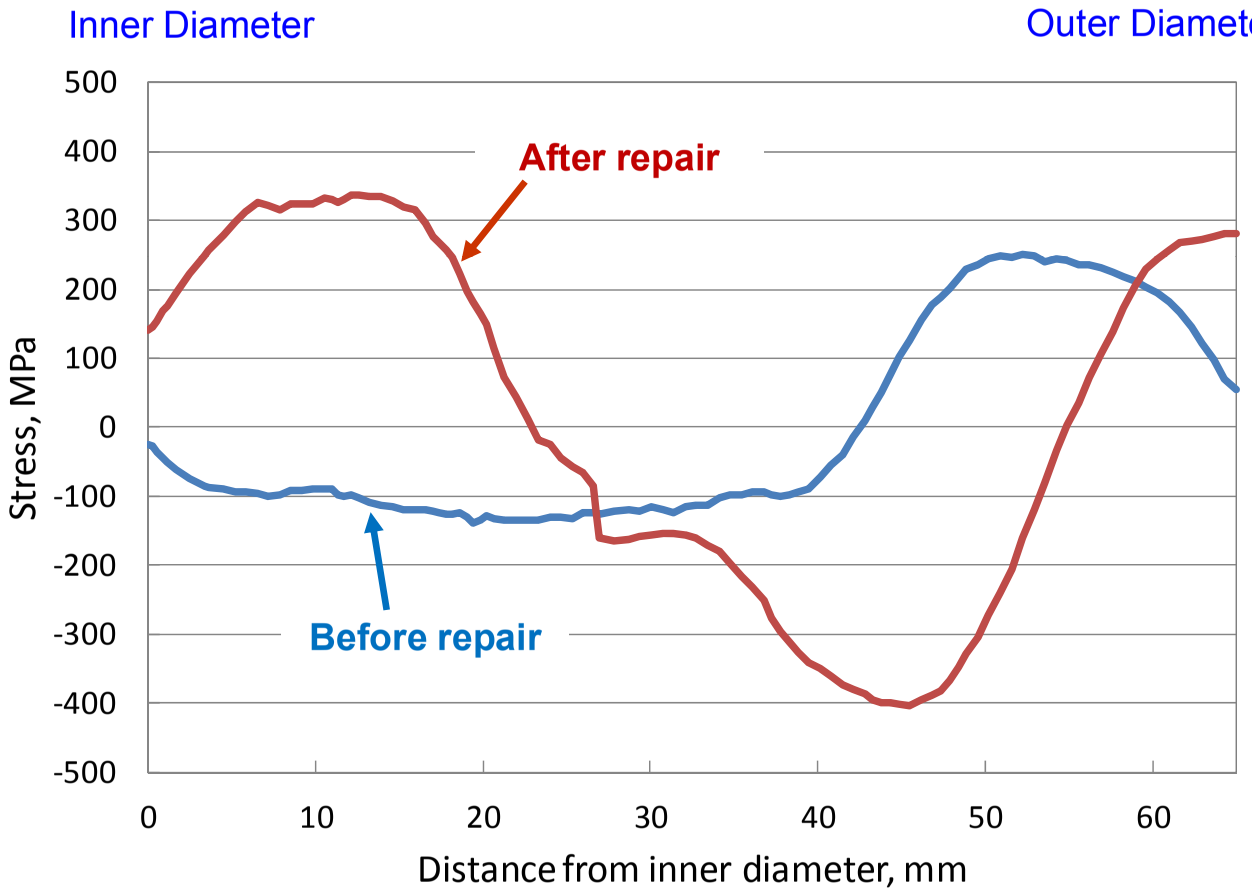
Stress Results

Narrow Gap Weld Analysis

- Axial stresses along butter to weld fusion line



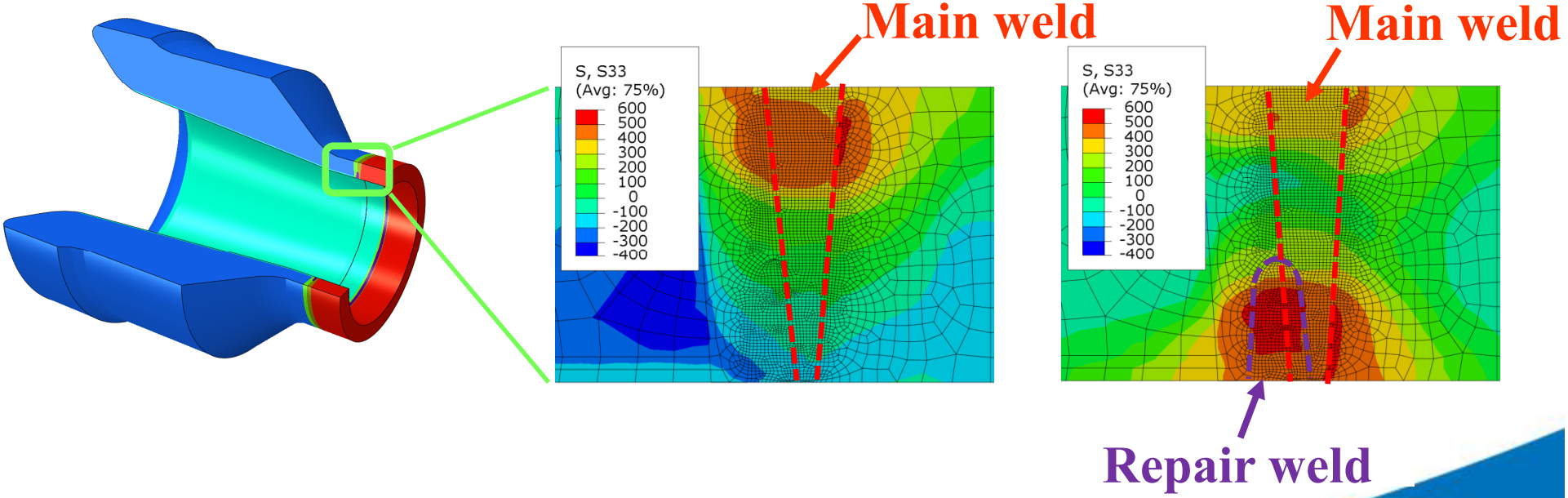
Path for stress distributions



Stress Results

Narrow Gap Weld Analysis

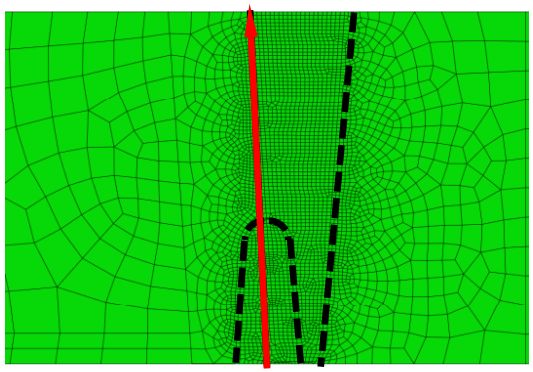
- Hoop stresses before and after repair weld



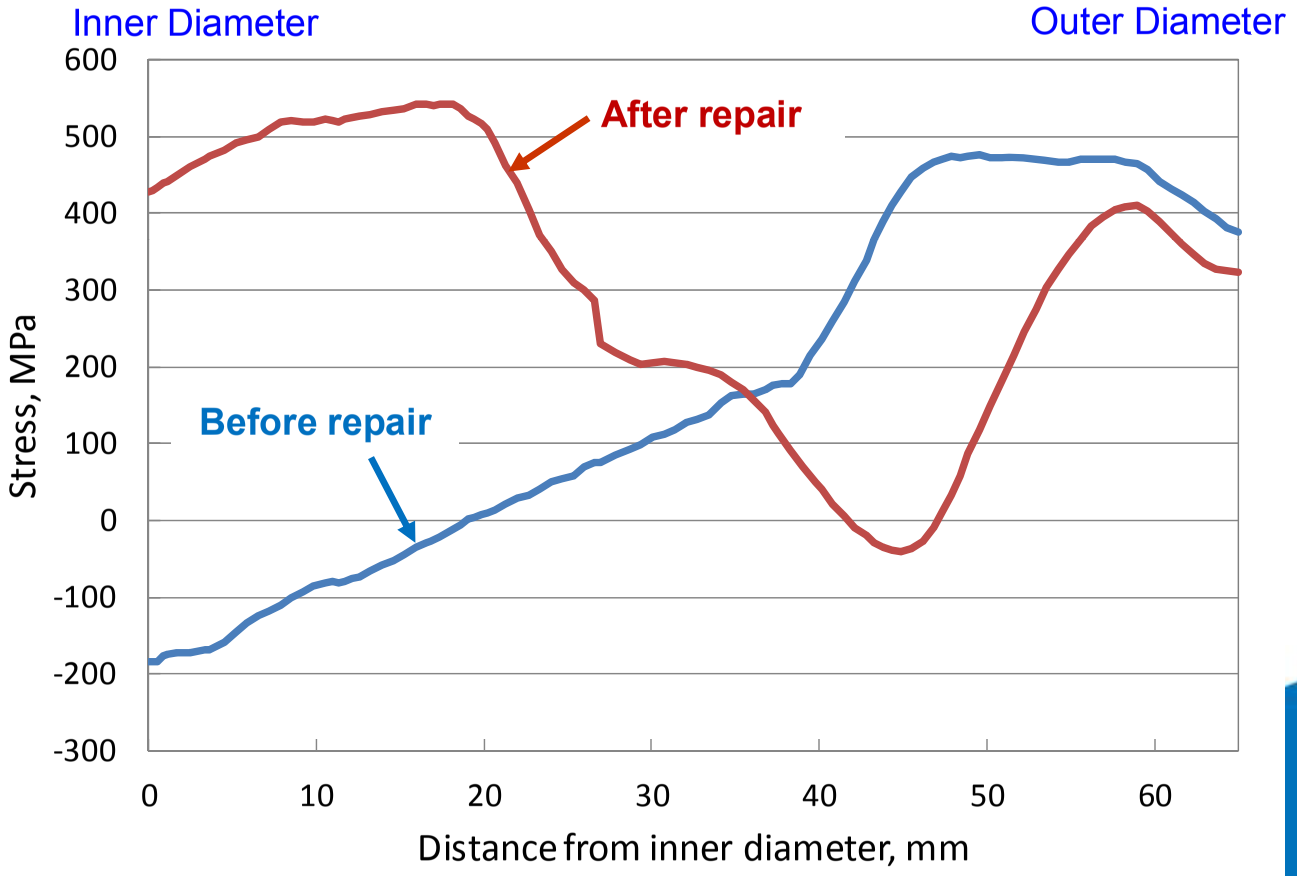
Stress Results

Narrow Gap Weld Analysis

- Hoop stresses along butter to weld fusion line



Path for stress distributions



Discussion

Narrow Gap Weld Analysis

- FE analysis shows significant stress increase near inner diameter due to repair
- Consistent with previous analysis and measurements
  - Weld Residual Stress Validation Program
    - Cooperative with nuclear industry under Memorandum of Understanding Addendum
  - Pressure Vessels and Piping Conference publications
  - Journal of Pressure Vessel Technology publications
- Reasonable assurance in the calculated residual stress shift due to weld repair

Discussion

Narrow Gap Weld Analysis

- Analysis completed represents the current, as-welded condition

- Additional analysis would be required to perform a fitness-for-service flaw evaluation
  - Safe end to pipe stainless steel weld
    - May or may not effect the dissimilar metal weld stress distribution
    - Heavily dependent on geometry of safe end
  - Operating conditions
    - Pressure and temperature
    - Deadweight, thermal expansion, design basis loads

Conclusions

Narrow Gap Weld Analysis

- Repair significantly alters through-wall residual stresses in the as-welded condition
- Hoop and axial stresses are greatly increased at ID and inner half of through-wall thickness
- Mixed isotropic-kinematic strain hardening assumption leads to reasonable stress magnitudes
- Stainless steel weld and operating loads may effect dissimilar metal weld stress distributions